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Blind Selective Mapping in Preamble-Based OFDM for PAPR Reduction

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ABSTRACT

High demand for a perfect and flawless communication system is one of the reasons why researches are trying hard to find the best solution for the issues faced by OFDM. One of the biggest problems is high PAPR value that can introduce all kind of distortions and interferences to the system and eventually threatening OFDM position in future technologies. Selective mapping was proven to be able to reduce PAPR value in OFDM without introducing any kind of distortion to the system but the need for side information transmission will reduce the efficiency of OFDM. In this paper, maximum likelihood estimation was utilized to recover the data transmitted to the receiver without the need of SI transmission. Preamble based OFDM was used to assure time synchronization in the system. PAPR value was greatly reduced by using SLM and increase proportionally with the number of subcarriers. BER of the system manged to be improved by the implementation of preamble and ML estimation though the performance degrades as the number of preamble increases.

1. Introduction

Recent technologies such as 4G, Long Term Evolution (LTE), Wi-Fi, 5G, and many more depends on the Orthogonal Frequency Division Multiplexing (OFDM) system and demand for a perfect communication experience for the users in term of flexibility and scalability [1]. OFDM is able to fulfill the requirements needed by providing limitations of bandwidth and spectral efficiency, immune to impulse noise, increasing the speed of data rates and power of transmission, and enhancing Bit Error Rate (BER) performance. Just like the name, OFDM needs the subcarriers in the system to be orthogonal to each other so that the subcarriers will overlap each other and save bandwidth [2,3]. The used of Inverse Fast Fourier Transform (IFFT) in the system helps to improve the computational efficiency and maintain orthogonality. In OFDM, the serial frequency selective channel with high rate streams will be converted into parallel flat fading channels with low rate streams to combat the multipath fading effect, avoiding complex equalization and increase data rate and between each

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subcarrier are guard bands to avoid interferences [2,4]. However, this system still faces some weaknesses and the biggest one is high Peak to Average Power Ratio (PAPR) [3,5].

PAPR occurs when the parallel signals in OFDM are added up coherently and cause a sudden shoot up in output amplitude and cause power amplifier to go into non-linear region. In simple words, PAPR is the ratio of peak power to average power of a signal and expressed in dB. Intermodulation distortion will be introduced due to lack of orthogonality between subcarriers. BER and battery life will face degradation caused by channel interference. High PAPR can be reduced by using complicated Digital to Analog Converter (DAC) and High-Power Amplifier (HPA) but it will increase power consumption and become cost inefficient. Backing off power amplifier operation point will reduce the efficiency of the amplifier and cause low Signal to Noise Ratio (SNR) at the receiver [6]. These are the reasons why high PAPR ought to be reduced for making OFDM an efficient system [3]. There are many studies done to find the right PAPR reduction technique and some of it are clipping and filtering, coding, partial transmit sequences (PTS), selected mapping (SLM), tone injection, tone reservation and many more. SLM is one of the most effective and distortion less technique [5].

In SLM, random phase sequences are multiplied to input data sequences and produce new data sequences and data sequence with the lowest PAPR value will be chosen to be transmitted. This can help prevent the occurrence of high peak power [7,8]. At receiver, the received data sequence will be multiplied with conjugate phase sequences to retrieve the original data. To do this, index of the phase sequence corresponding to the chosen data sequence need to be transmitted as side information (SI) which can reduce power efficiency of the system [5,6,9]. To solve this issue, blind selective mapping (BSLM) has been proposed [10-12]. BSLM embedded SI to the signal using noise margin instead of subcarriers [13]. In this paper, we use preamble structure for timing synchronization and carrier frequency offset (CFO) estimation at the start of transmitter's frame. Preamble is a structure made of several repetitive sequences that are acknowleged by both transmitter and receiver and can help to mitigate the effect of intersymbol interferences (ISI) and multipath fading [14,15]. Maximum Likelihood (ML) estimation is used to decode the data sequence transmitted to the receiver without having to transmit SI index of the selected sequence. The transmitted sequence can be recovered by finding the minimum Euclidean distance between two constellations. The rest of the paper will be followed by methodology, result and discussion and conclusion.

2. Methodology

In this paper, data are transmitted in frames that include preamble L_p, cyclic prefix L_c, and data symbols L_d. To indicate that the average power of preamble equal to average power of data, preamble subcarriers that have been through QPSK modulation have been set to $S_{i,n} \in \sqrt{\frac{L_p}{L_d}}(\pm 1, \pm j)$ and then converted to time domain by IFFT. The transmitted preamble sequence can be represented by the following equation [14]

$$s_n = \sum_{k=0}^{N-1} S_k e^{j2\pi kn/N}$$

The data sequences are modulated into N equally spaced subcarriers. input data sequences of the system can be known as $X = [X_0, X_1, \dots, X_{N-1}].^T$. IFFT converts the signals to time domain as $x = [x_0, x_1, \dots, x_{N-1}]^T$ where the subcarrier spacing is $\Delta f = 1/NT$. The signals can be represented by the following equation [3]

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi\Delta ft} ; 0 \leq t \leq NT$$

U data sequences, each with length N, $P^u = [P_0^u, P_1^u, \dots, P_{N-1}^u]$ and carry the same information are generated in SLM and passed to IFFT to be converted to time domain. Once the data sequences are multiplied with the phase sequences, the signal can be represented by the following equation [16,17]

$$x^u(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x_n p_n^u e^{j2\pi\Delta ft}$$

The data sequence with the lowest PAPR value is chosen to be transmitted by the following equation [18]

$$x = \arg\min x_n$$

The peak power produced when N channels are added together in phase is N-times the usual power [3]. PAPR can be calculated by the following equation [6, 7]

$$PAPR = \frac{[max|x_n|^2]}{E[|x_n|^2]}$$

Where $[max|x_n|^2]$ is the maximum instantaneous power and $E[|x_n|^2]$ is the average instantaneous power across the subcarriers. To study the performance of PAPR reduction technique, Complementary Cumulative Distribution Function (CCDF) is used. CCDF is the measure of the probability of PAPR exceeding the threshold set and can be expressed by the following equation [7]

$$CCDF(N, PAPR_0) = \rho_r\{PAPR > PAPR_0\} = 1 - (1 - (1 - e^{-PAPR}))^N$$

Where $PAPR_0$ is a fixed number of PAPR and N is the amount of subcarriers. At the receiver, steady state of the preamble signal can be represented as [19]

$$r_{k,l_1} = s_1 h_k + w_{k,l_1}$$

Where k is the number of frames, l is the number of channel path and s_1 can be represented by the following equation

$$s_1 = \left[\left(L_p - L_{hr} + 1\right) X \; L_{hr}\right] matrix$$

Where L_{hr} is the channel length assumed by the receiver. Channel estimation of the proposed method can be calculated as

$$h_k = (s_1^H s_1)^{-1} s_1^H r_{k,l_1}$$

Once channel estimation executed, the preamble and CP are removed from the signal received and FFT is used to convert the signal to frequency domain. ML estimation is used to find the minimum Euclidean distance of constellation point in the received signal and the original constellation by utilizing the following equation

$$X_u = \sum_{n=0}^{N-1} \min|x_n p_n^u - \mathbb{C}|^2,$$

Where $\mathbb{C}$ is the original constellation points. Figure 1 and Table 1 show the flowchart and parameters of the proposed method in this paper respectively.

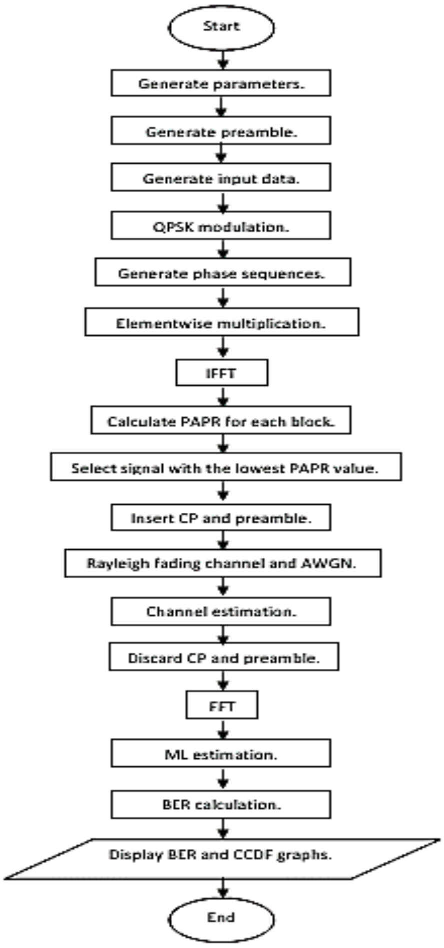

Fig. 1. Flowchart of the proposed method

Table 1
Parameters used in the proposed method

Parameter	Value
SNR	40dB
Number or frames	1000
FFT length	128,256,512,1024
Channel length	10
Preamble length	64,128,256,512
Cyclic prefix length	9
Number of subcarriers	256,512,1024,2048
Number of blocks	32
Channel	Rayleigh fading
Noise	AWGN

3. Results

The value of SNR used in this study is 40dB since it provides the best BER performance. Any decibels higher than that doesn't work on the algorithm and decibels lower than 40 dB degrade the BER performance. Figure 2 shows the CCDF performance of PAPR in OFDM signal with SLM and without SLM. OFDM with SLM that include ML estimation provide a huge improvement in PAPR performance compared to OFDM signal only. Table 2 provides PAPR value with different number of subcarriers in the signal with and without SLM. The number of blocks used in table 2 is 32. In both signals, PAPR value increase as the number of subcarriers increase. This is due to increase in number of computation due to the number of subcarriers and the number of signals that need to be added up coherently in the amplifier.

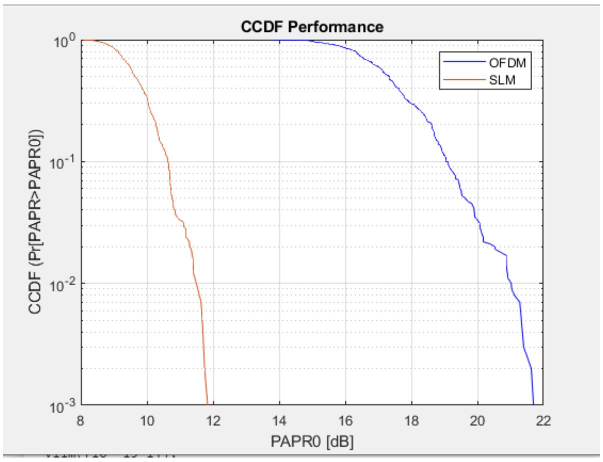

Fig. 2. PAPR performance of OFDM signal with and without SLM

Table 2
PAPR performance with different number of subcarriers

Number of subcarriers	OFDM with preamble (dB)	SLM with preamble (dB)
256	15.219	7.365
512	16.393	8.129
1024	17.268	8.742
2048	17.585	10.336

Figure 3 shows the BER performance of OFDM signal with and without preamble also SLM with and without ML estimation. The number of subcarriers and blocks used in figure 3 are 1024 and 32 respectively. OFDM has lower BER when preamble is included in the algorithm and SLM with ML estimation can provide better BER performance compared to SLM without ML estimation. OFDM with preamble can provide time synchronization to the system which explain why it has lower BER compared to the OFDM without preamble. When SNR is between 0-20dB, the BER performances are almost the same for conventional SLM and BSLM but as the SNR increase, BSLM signal proves to deliver a better BER performance, and this might be due to the lower complexity given by the estimation without degrading PAPR and BER performance. Figure 4 shows BER performance of OFDM with different number of preambles. BER degrades as preamble increase due to increase in number of computations and increase the chance of estimation error that will introduce interferences to the system.

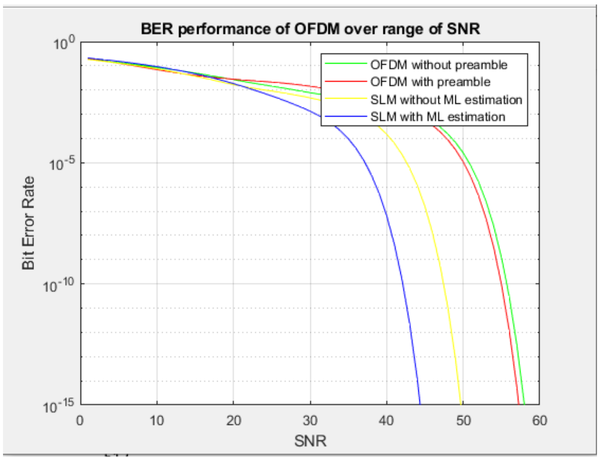

Fig. 3. BER performance of OFDM signals

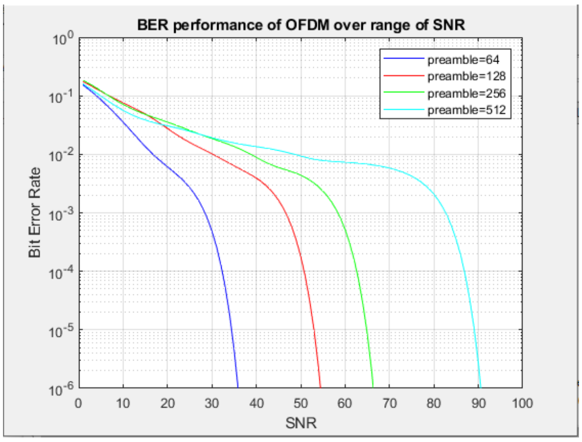

Fig. 4. BER performances with different number of preambles

4. Conclusions

In this paper, we used preamble based OFDM for time synchronization in the system and improve the BER performance of the system. SLM was chosen as PAPR reduction technique and as can be seen from the above section, it manages to reduce PAPR value without distortion and provide a better BER performance. To avoid SI transmission in order to maintain the efficiency of the system, ML estimation was used in the receiver to retrieve the data transmitted. The utilization of ML estimation manages to improve BER performance of the system further.

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